Modeling and Simulation Comparison between IKONOS, Landsat 5, and Landsat 7 MSI Systems

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Outline- Comparison of MSI Systems

- What we're doing, and why
- Methodology
- Spectral Response Differences
- Surface Reflectances
- Atmospheric Terms
- TOA Radiances
- Band Convolved Band Comparisons
- How these simulations are useful

What We're Doing, and Why

- What we're doing: Simulating And Comparing Spectral Sensor Measurements
  - Incorporates Physical Models and Best Available Measurements
  - Provides Control Over Scene Materials, Surface Illumination, Atmospheric Parameters, Viewing Geometry, and Sensor Specifications
- Why:
  - Gain Understanding of How Same Materials Will Appear to Different Sensors
  - Gain Understanding of How Same Materials Will Appear Under Different Conditions (Time of Day, Day of Year, Atmospheric Conditions, Viewing Geometry, etc.)

What We're Doing, and Why

- Why: (Continued)
  - Gain Understanding of How Sensor Characteristics (Band Placement, Spectral Resolution, Number of Bands, Signal to Noise Ratio, etc.) Impact on Resulting Data
  - Generate Synthetic Data Cubes From Theoretical or Not-Yet-Built Sensors For Evaluation

- Supports NIMA's (National Imagery and Mapping Agency) Participation in the Joint Agency Commercial Imagery Evaluation (JACIE) Team

Methodology

- Modtran 3.7, embedded in the Spectral Architecture Evaluation Software (SAE tool) to calculate downwelling sun radiances- direct and diffuse (can be calculated as functions of elevation and azimuthal angles), atmospheric transmittances for incoming and outgoing paths, and upwelling solar scattered radiances

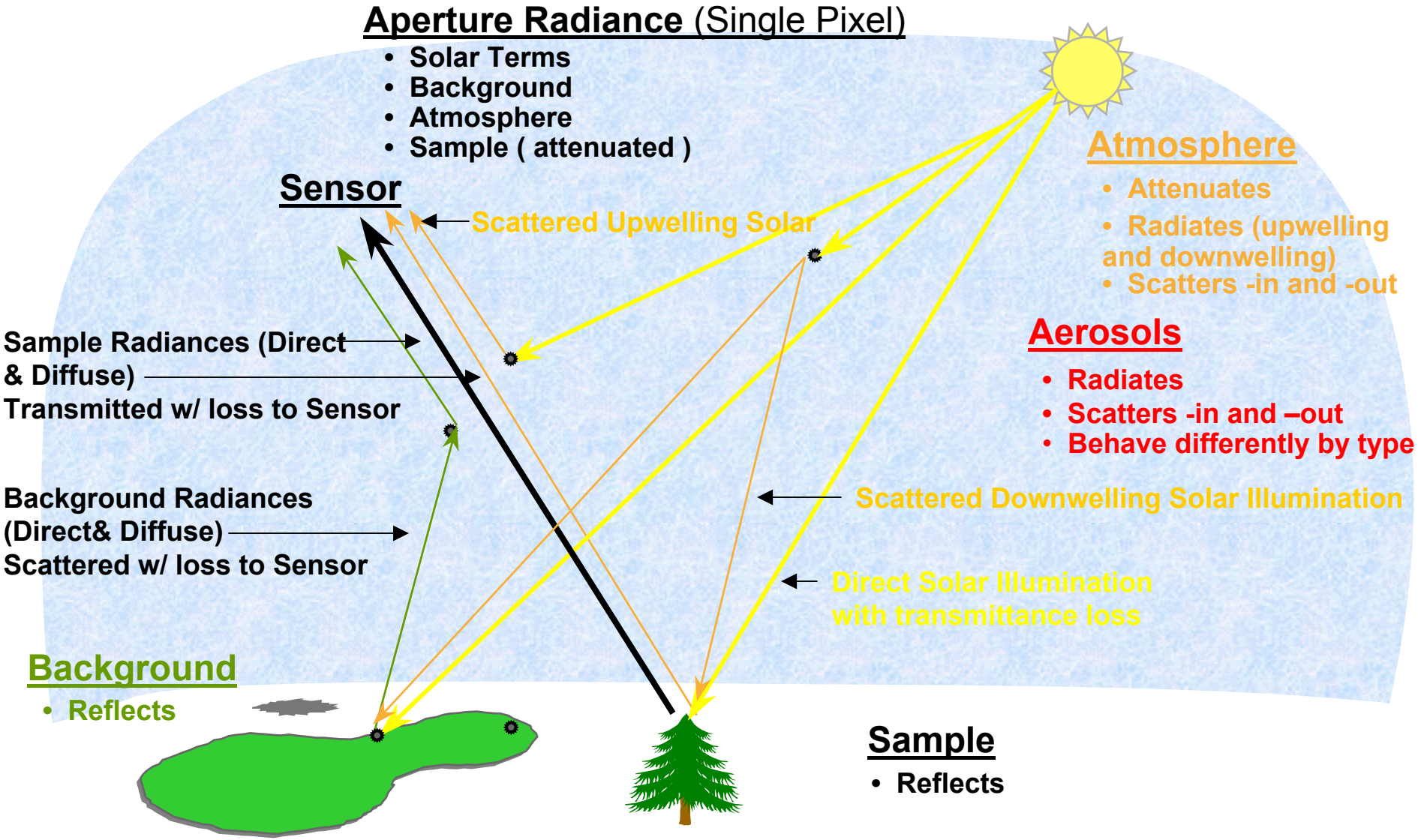
- ASTER(Advanced Spaceborne Thermal Emission and Reflection Radiometer) or NEF (Non-conventional Exploitation Factors) Spectral Database for surface reflectances (several hundred materials each)

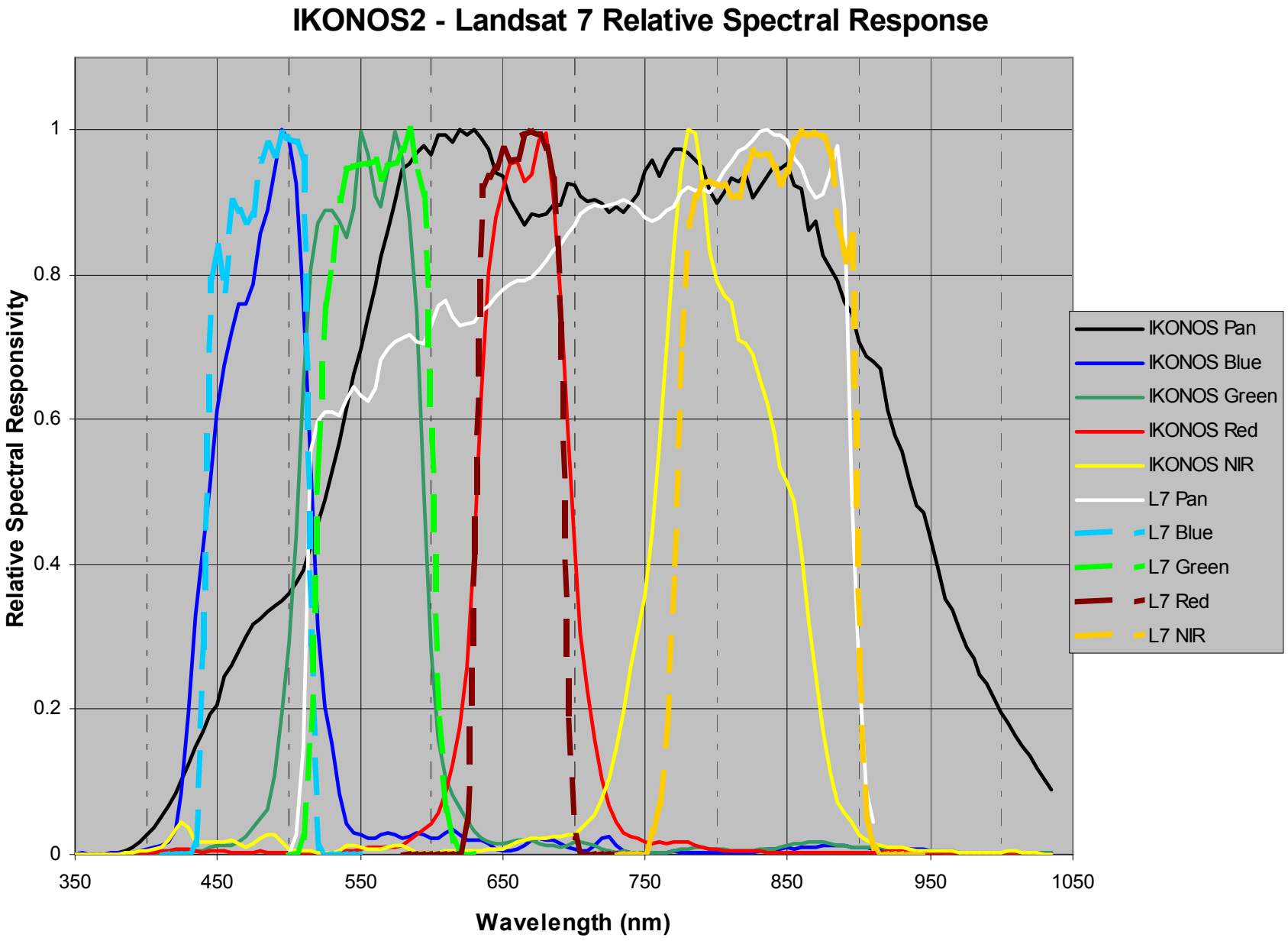
- Convolved Top of Atmosphere (TOA) spectral radiances with sensor response functions to calculate MSI in-band radiances

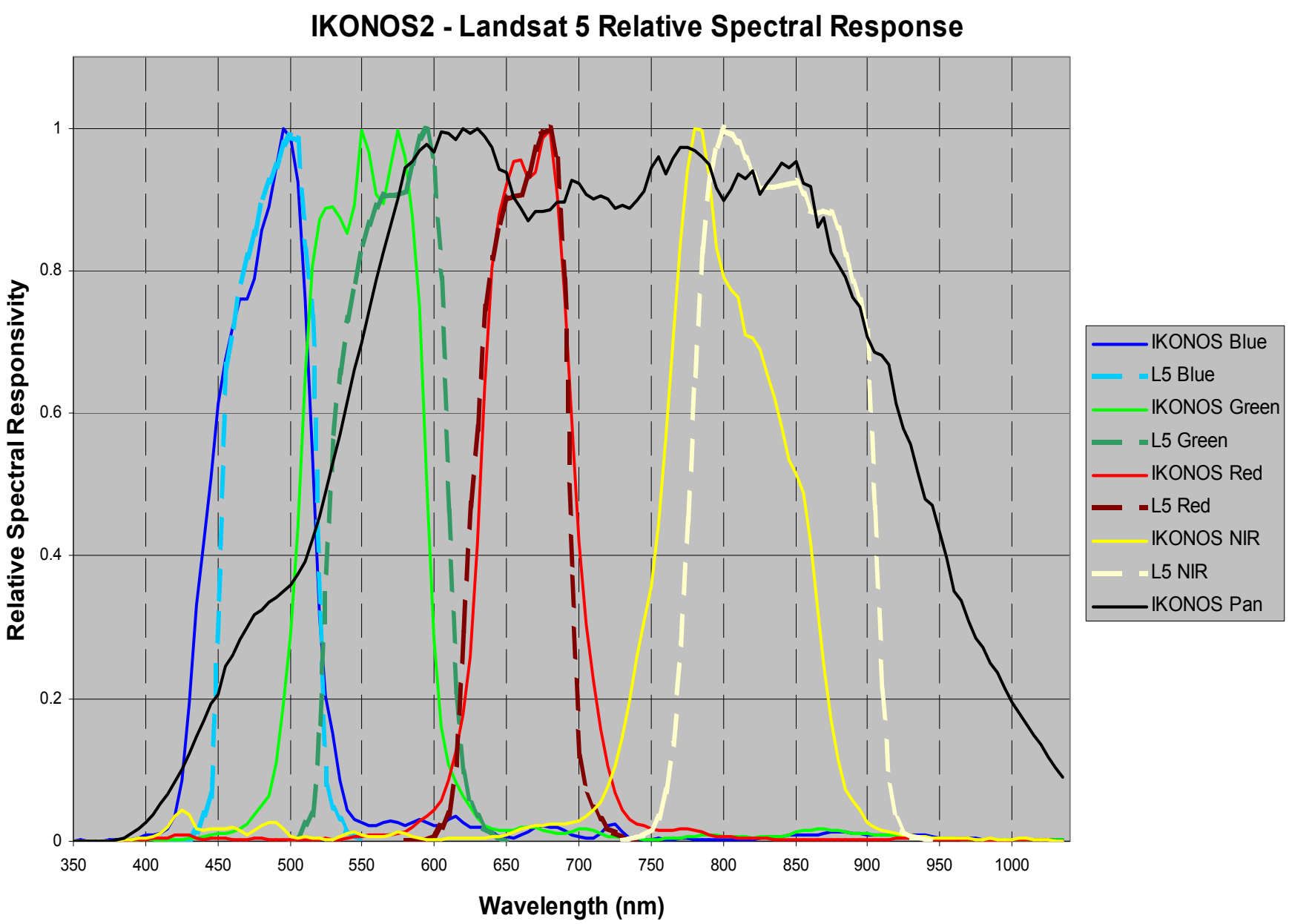
- Can (but did not yet) add in SNR and calibration effects

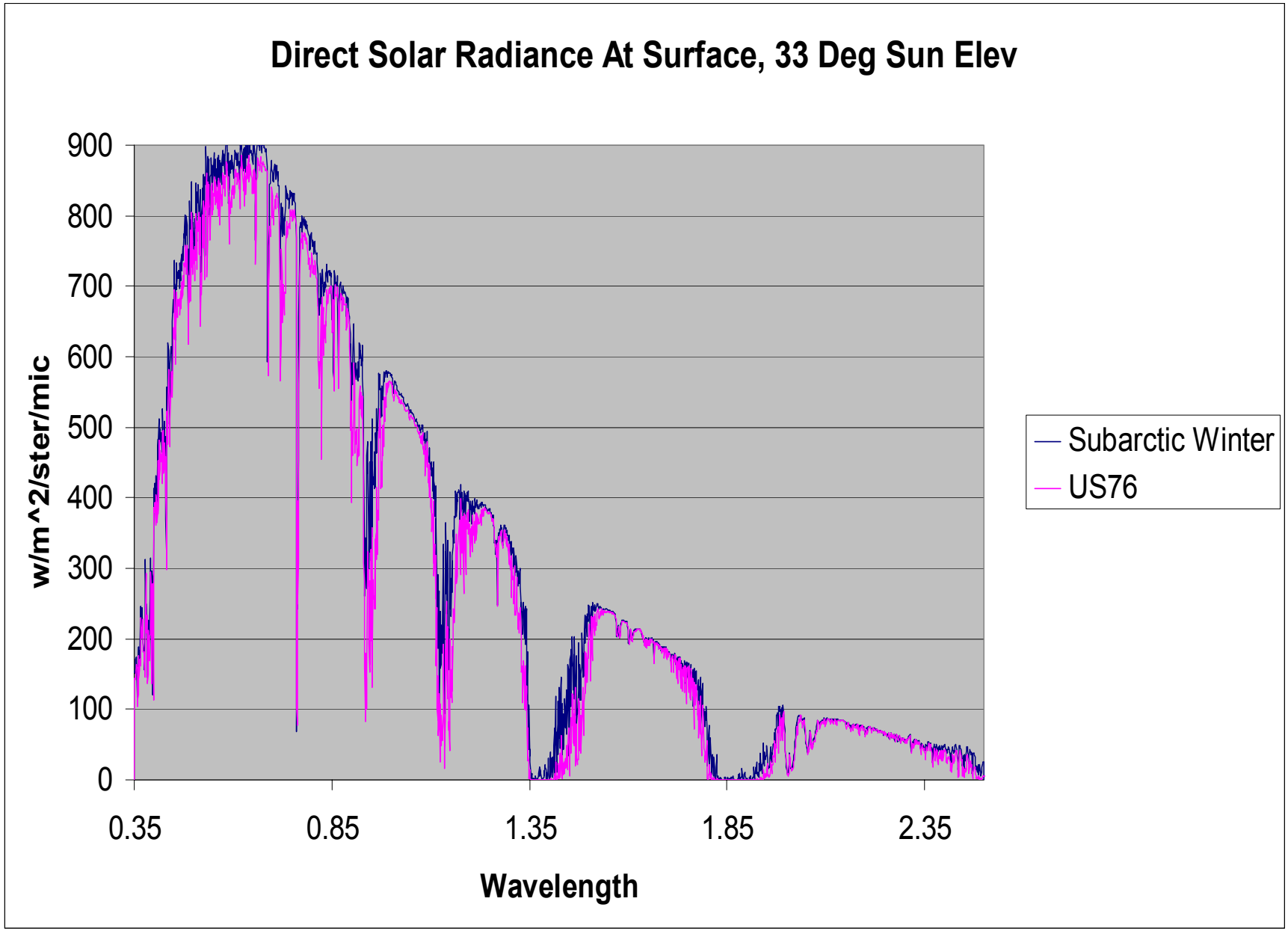
- MSI in-band TOA radiances can be atmospherically corrected (with imperfect knowledge), and fed into exploitation algorithms

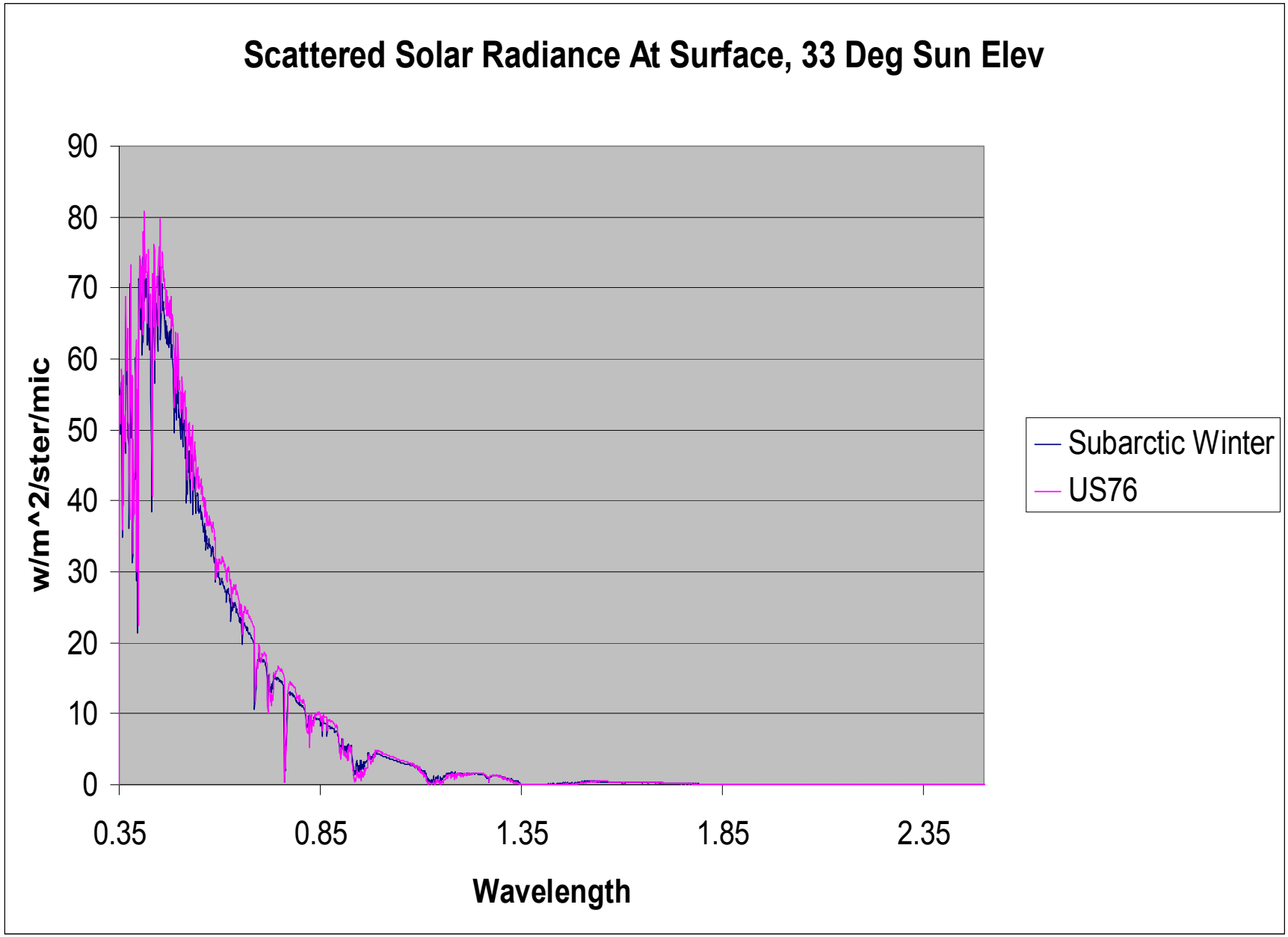
Radiometric Environment-Reflective

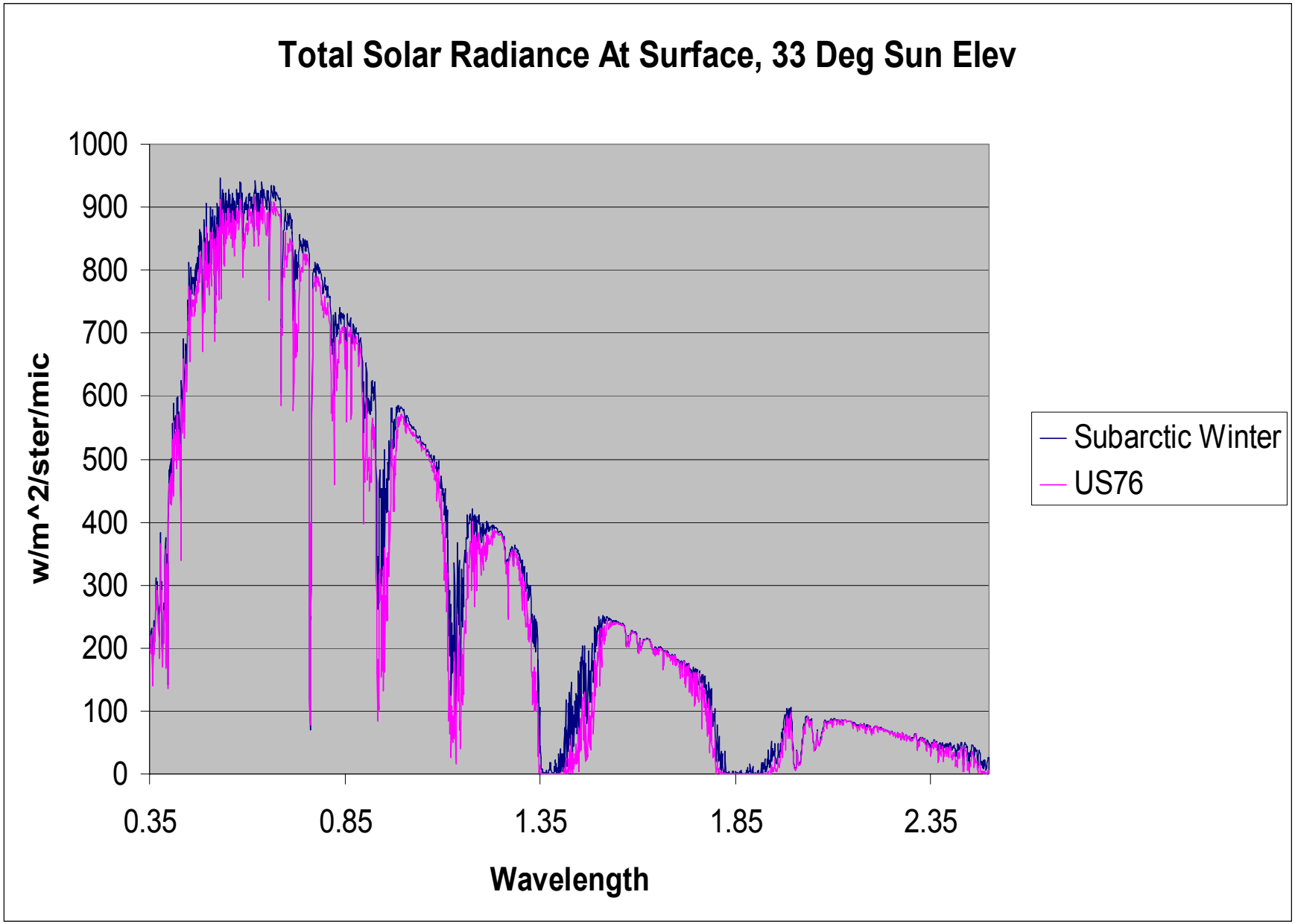


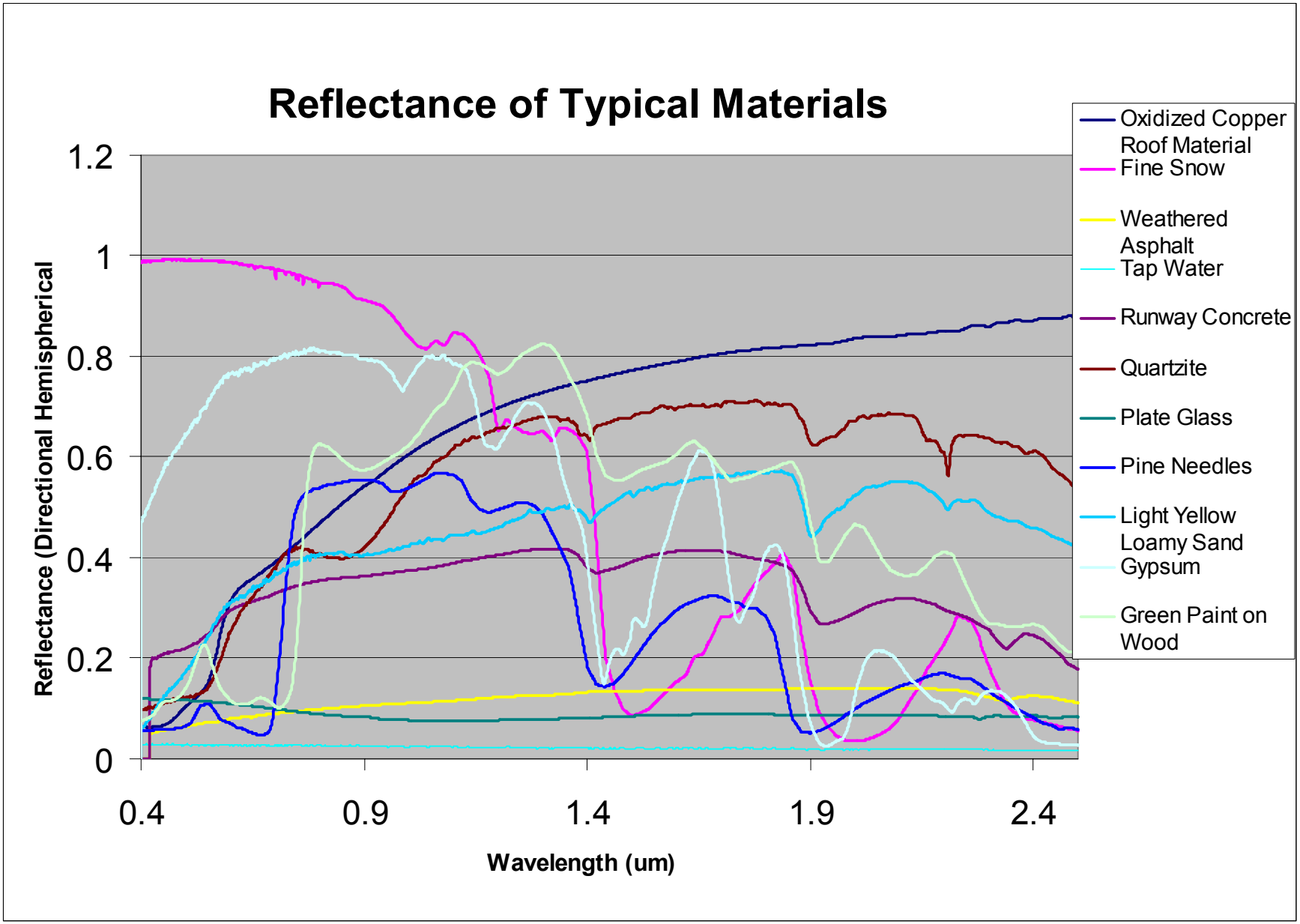

IKONOS2 - Landsat 7 Relative Spectral Response
Relative Spectral Responsivity
Wavelength (nm)
0
0.2
0.4
0.6
0.8
1
350
450
550
650
750
850
950
1050
IKONOS Pan
IKONOS Blue
IKONOS Green
IKONOS Red
IKONOS NIR
L7 Pan
L7 Blue
L7 Green
L7 Red
L7 NIR


IKONOS2 - Landsat 5 Relative Spectral Response
Relative Spectral Responsivity
0
0.2
0.4
0.6
0.8
1
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
Wavelength (nm)
IKONOS Blue
L5 Blue
IKONOS Green
L5 Green
IKONOS Red
L5 Red
IKONOS NIR
L5 NIR
IKONOS Pan

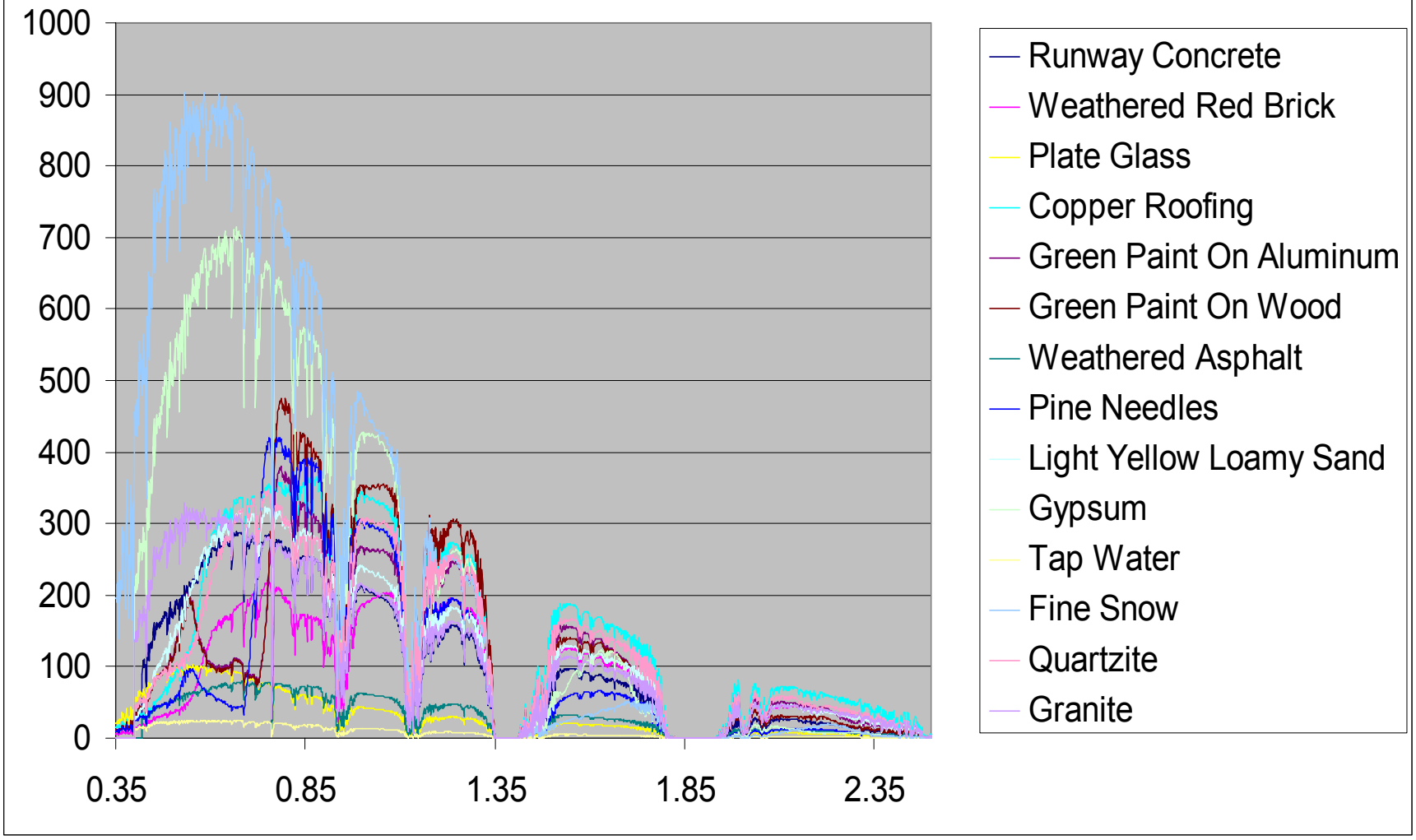

Direct Solar Radiance At Surface, 33 Deg Sun Elev
w/m^2/ster/mic
900
800
700
600
500
400
300
200
100
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Subarctic Winter
US76

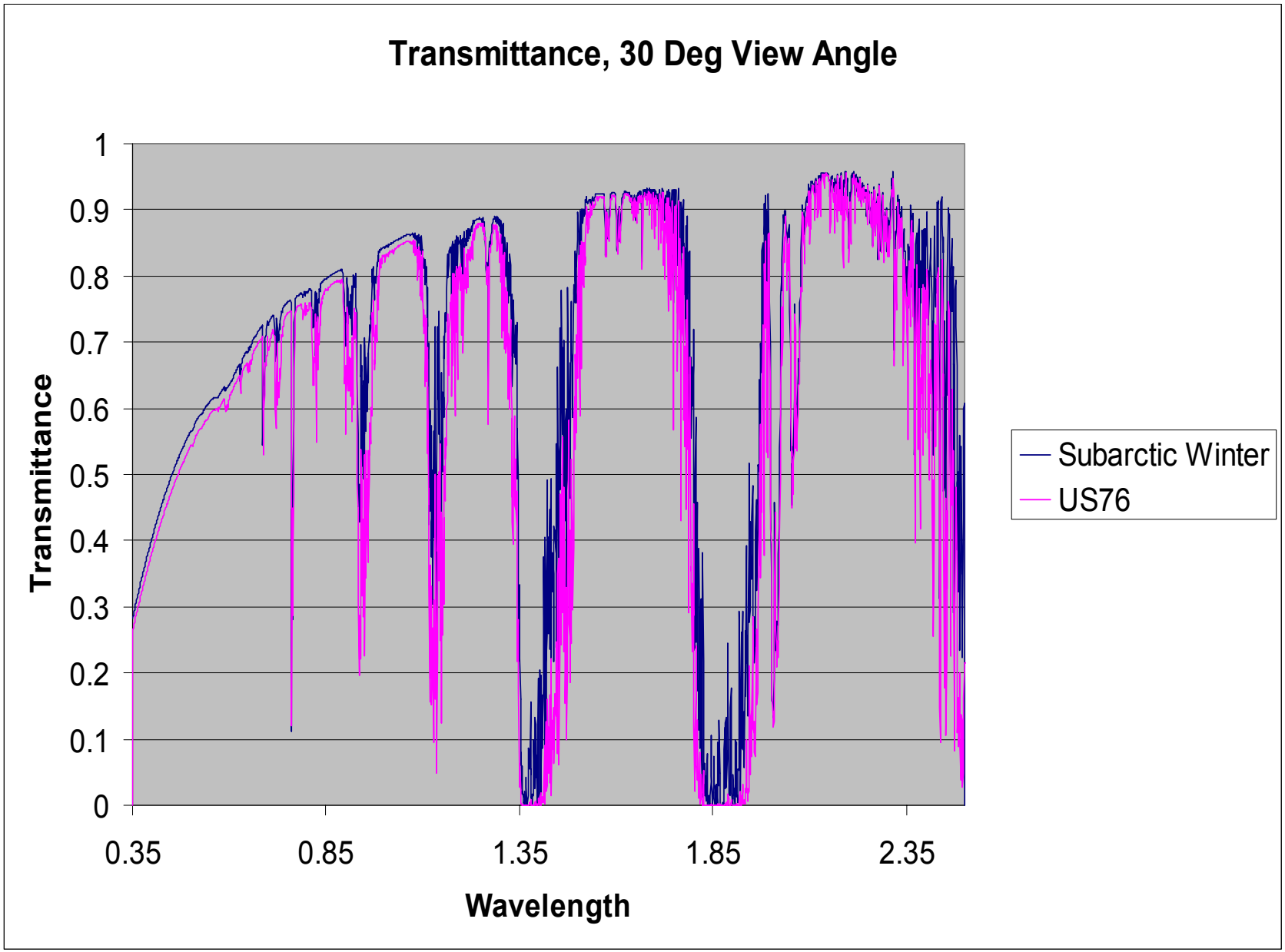

Scattered Solar Radiance At Surface, 33 Deg Sun Elev
w/m^2/ster/mic
90
80
70
60
50
40
30
20
10
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Subarctic Winter
US76

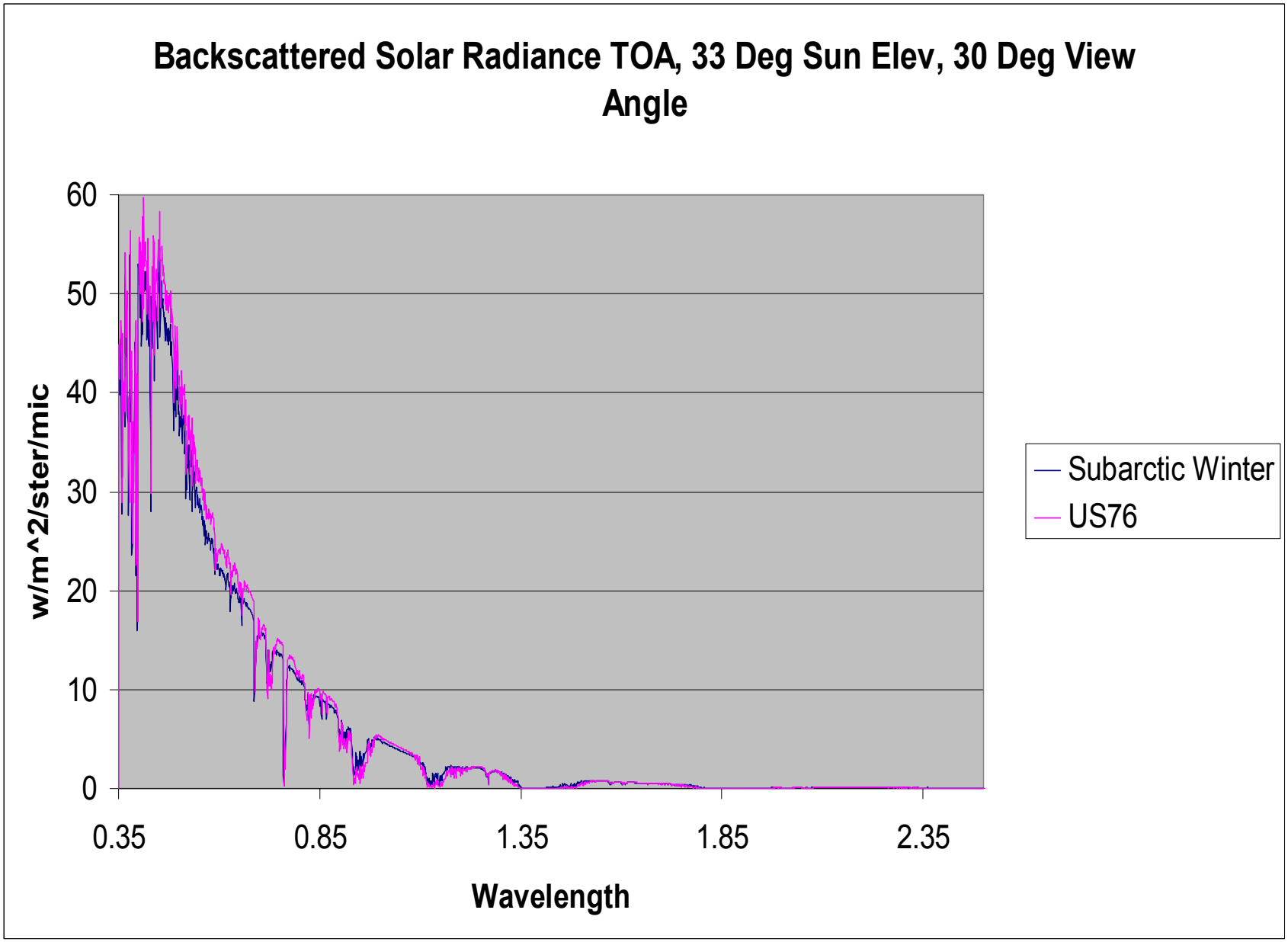

Total Solar Radiance At Surface, 33 Deg Sun Elev
w/m^2/ster/mic
1000
900
800
700
600
500
400
300
200
100
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Subarctic Winter
US76

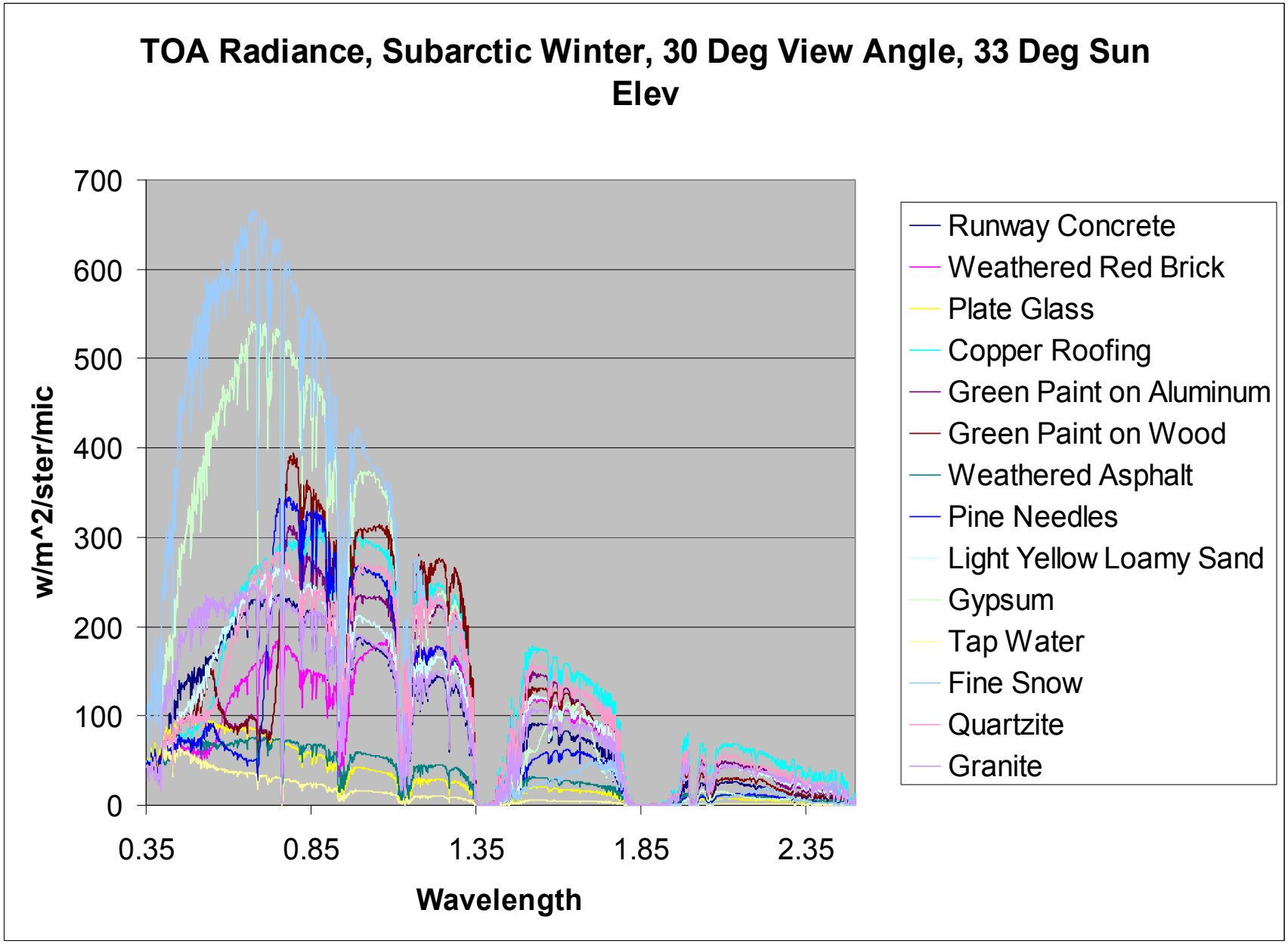

Reflectance of Typical Materials
Reflectance (Directional Hemispherical
1.2
1
0.8
0.6
0.4
0.2
0
0.4
0.9
1.4
1.9
2.4
Wavelength (um)
Oxidized Copper Roof Material
Fine Snow
Weathered Asphalt
Tap Water
Runway Concrete
Quartzite
Plate Glass
Pine Needles
Light Yellow Loamy Sand
Gypsum
Green Paint on Wood

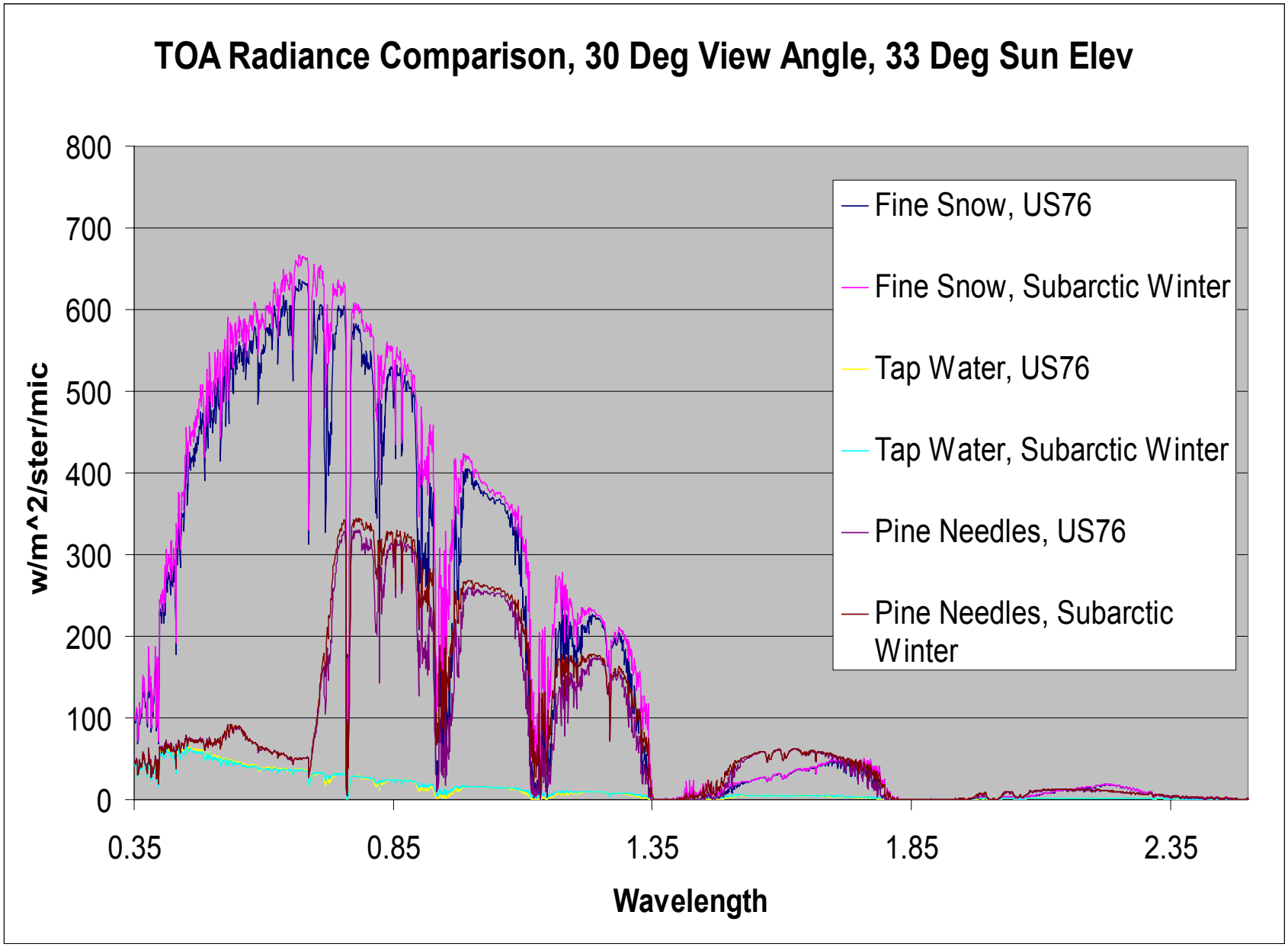
Surface Leaving Radiance For Various Materials, US76, 33 Deg Sun Elev.



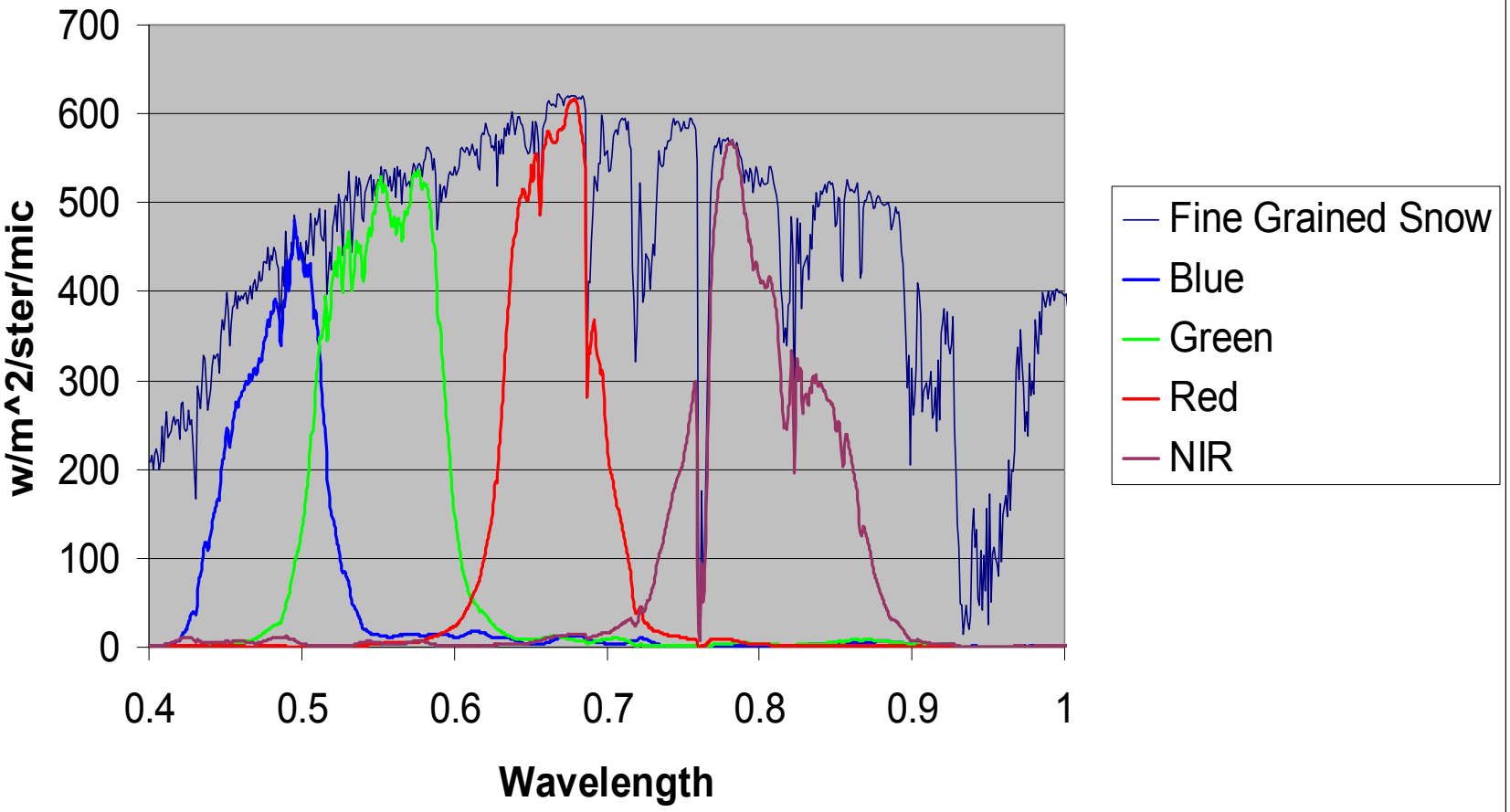

Transmittance, 30 Deg View Angle
Transmittance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Subarctic Winter
US76

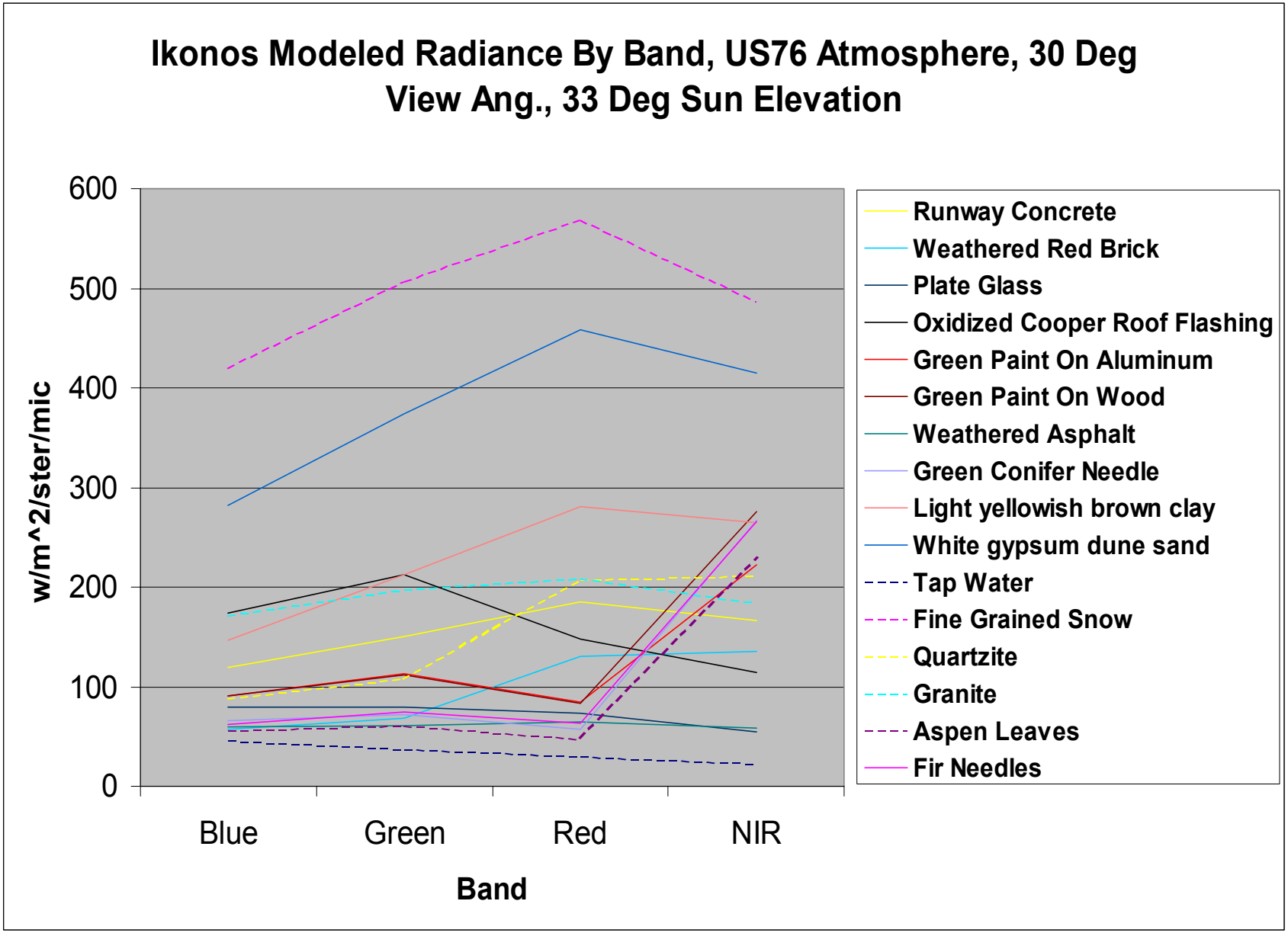

Backscattered Solar Radiance TOA, 33 Deg Sun Elev, 30 Deg View Angle
w/m^2/ster/mic
60
50
40
30
20
10
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Subarctic Winter
US76


TOA Radiance, Subarctic Winter, 30 Deg View Angle, 33 Deg Sun Elev
w/m^2/ster/mic
700
600
500
400
300
200
100
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Runway Concrete
Weathered Red Brick
Plate Glass
Copper Roofing
Green Paint on Aluminum
Green Paint on Wood
Weathered Asphalt
Pine Needles
Light Yellow Loamy Sand
Gypsum
Tap Water
Fine Snow
Quartzite
Granite

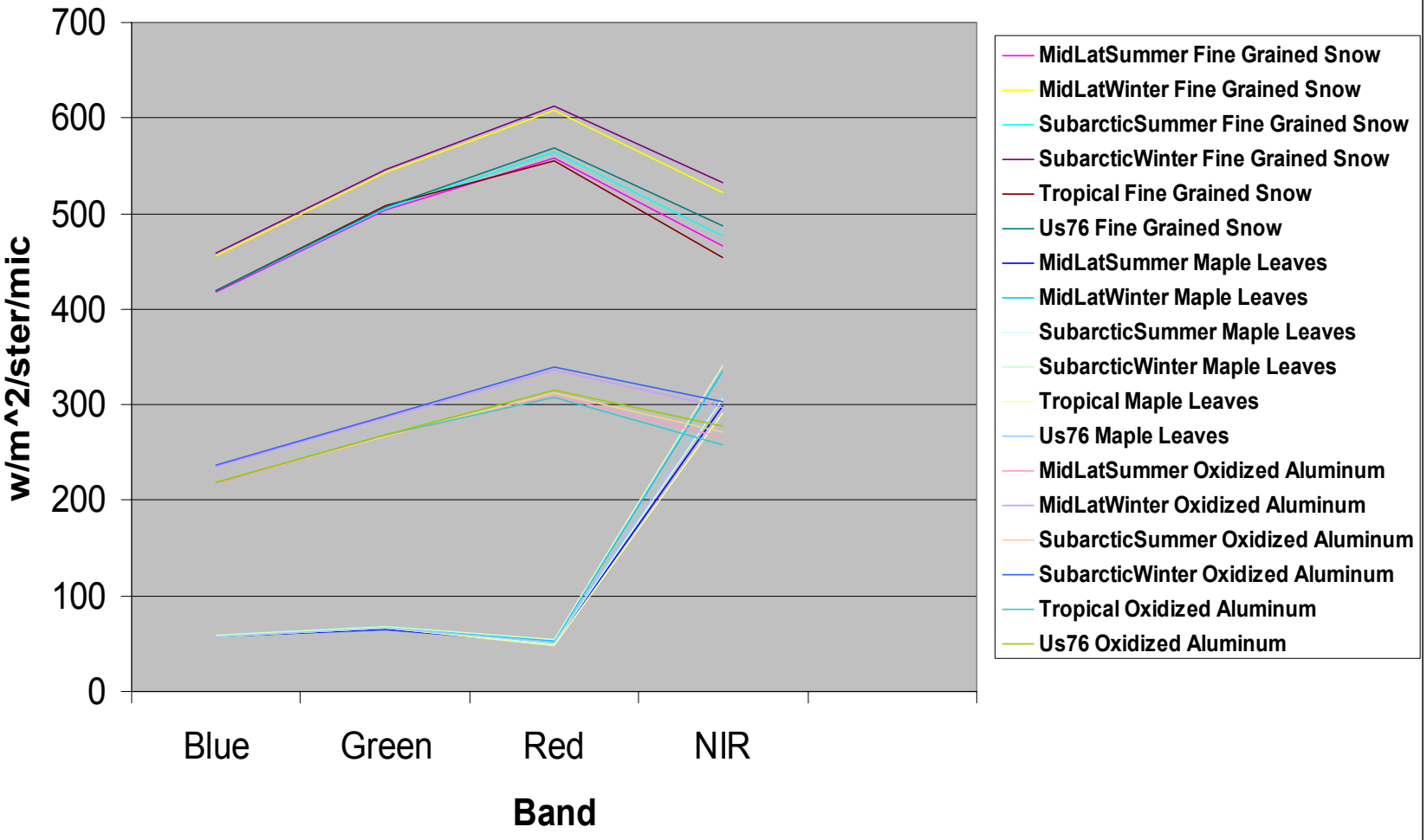

TOA Radiance Comparison, 30 Deg View Angle, 33 Deg Sun Elev
w/m^2/ster/mic
800
700
600
500
400
300
200
100
0
0.35
0.85
1.35
1.85
2.35
Wavelength
Fine Snow, US76
Fine Snow, Subarctic Winter
Tap Water, US76
Tap Water, Subarctic Winter
Pine Needles, US76
Pine Needles, Subarctic Winter

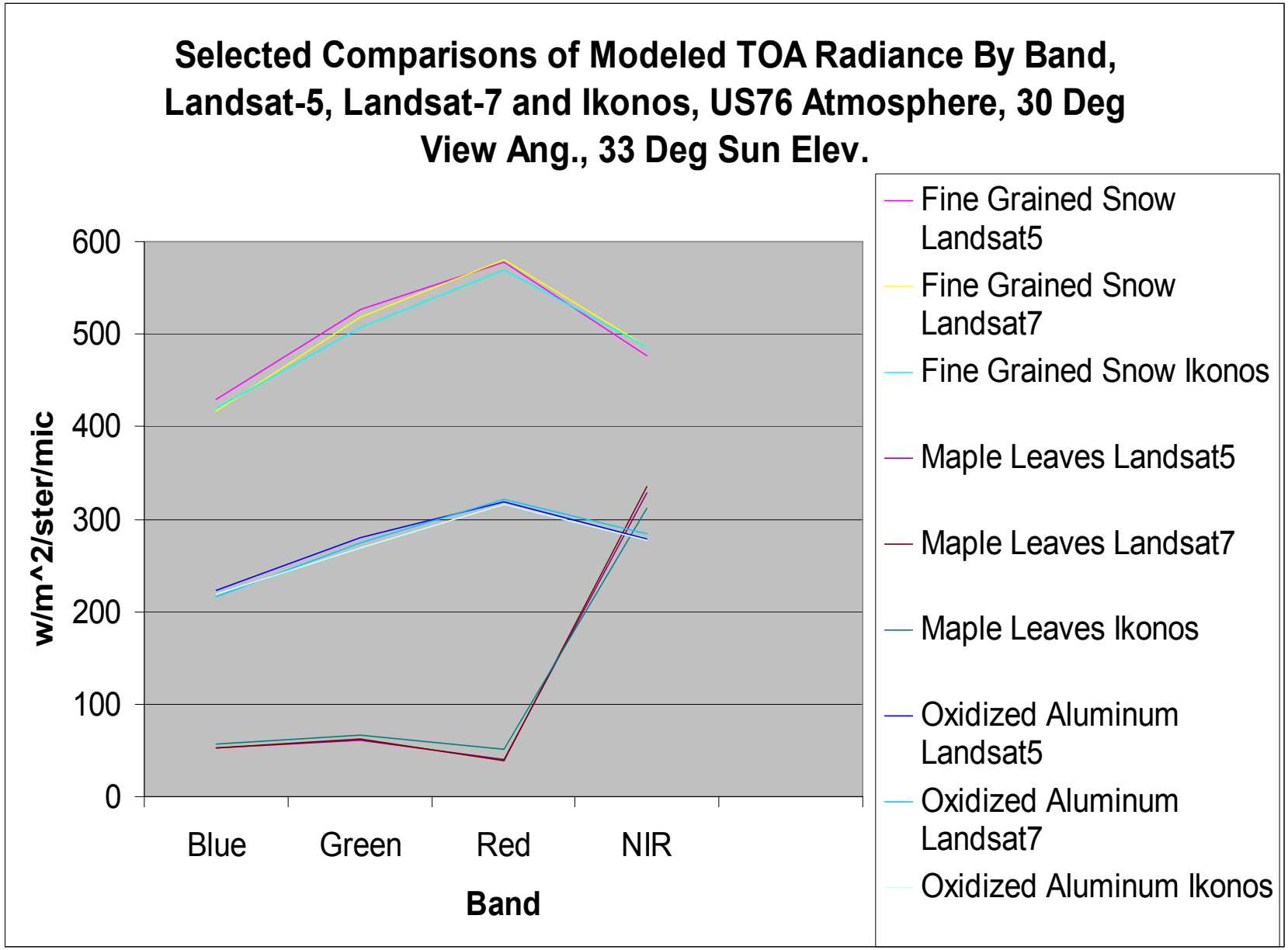
Ikonos Band Response Functions Convolved With TOA Radiance for Fine Grained Snow, US76 Atmosphere, 30 Deg View Ang., 33 Deg Sun Elev.




Ikonos Modeled Radiance By Band, US76 Atmosphere, 30 Deg View Ang., 33 Deg Sun Elevation
600
500
400
300
200
100
0
w/m^2/ster/mic
Blue
Green
Red
NIR
Band
Runway Concrete
Weathered Red Brick
Plate Glass
Oxidized Cooper Roof Flashing
Green Paint On Aluminum
Green Paint On Wood
Weathered Asphalt
Green Conifer Needle
Light yellowish brown clay
White gypsum dune sand
Tap Water
Fine Grained Snow
Quartzite
Granite
Aspen Leaves
Fir Needles

Ikonos Band Convolved TOA Radiance Comparison Between Atmospheres




Selected Comparisons of Modeled TOA Radiance By Band, Landsat-5, Landsat-7 and Ikonos, US76 Atmosphere, 30 Deg View Ang., 33 Deg Sun Elev.
w/m^2/ster/mic
600
500
400
300
200
100
0
Blue
Green
Red
NIR
Band
Fine Grained Snow Landsat5
Fine Grained Snow Landsat7
Fine Grained Snow Ikonos
Maple Leaves Landsat5
Maple Leaves Landsat7
Maple Leaves Ikonos
Oxidized Aluminum Landsat5
Oxidized Aluminum Landsat7
Oxidized Aluminum Ikonos

Comparison of Landsat 5, Landsat 7, and IKONOS Relative Band Radiances, US76 Atmosphere, 30 Deg View Ang., 33 Deg Sun Elev., 3 Materials

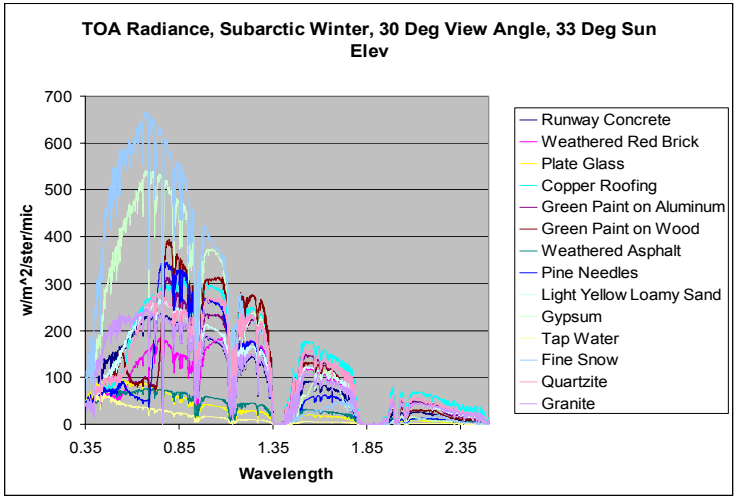
	Snow	Snow	Snow	Maple	Maple	Maple	Aluminum	Aluminum	Aluminum
	L5/L7	L7/Ikonos	L5/Ikonos	L5/L7	L7/Ikonos	L5/Ikonos	L5/L7	L7/Ikonos	L5/Ikonos
Blue	1.032083	0.99209	1.02392	1.001199	0.906605	0.907692	1.032955	0.983763	1.016183
Green	1.014119	1.023165	1.037612	0.964854	0.944719	0.911516	1.018232	1.022502	1.041144
Red	0.994158	1.019947	1.013988	1.046627	0.75054	0.785536	0.993702	1.018151	1.011738
NIR	0.979239	0.999092	0.97835	0.980001	1.072103	1.050662	0.9826	1.023728	1.005915

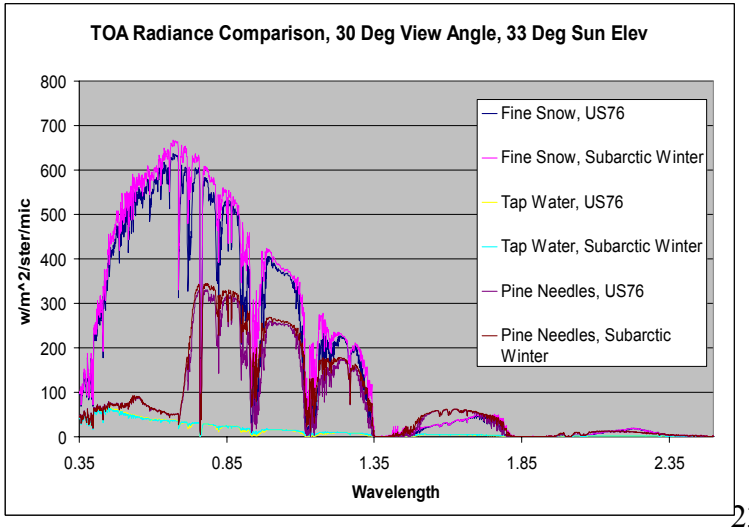
How these simulations are useful

- Tuning Algorithms for New Sensors, e.g., setting NDVI (Normalized Difference Vegetation Index) thresholds

	Snow L5/L7	Snow L7/Ikonos	Snow L5/Ikonos	Maple L5/L7	Maple L7/Ikonos	Maple L5/Ikonos	Aluminum L5/L7	Aluminum L7/Ikonos	Aluminum L5/Ikonos
Blue	1.032083	0.99209	1.02392	1.001199	0.906605	0.907692	1.032955	0.983763	1.016183
Green	1.014119	1.023165	1.037612	0.964854	0.944719	0.911516	1.018232	1.022502	1.041144
Red	0.994158	1.019947	1.013988	1.046627	0.75054	0.785536	0.993702	1.018151	1.011738
NIR	0.979239	0.999092	0.97835	0.980001	1.072103	1.050662	0.9826	1.023728	1.005915

- Sensor Design, Development and Optimization
  - Band Selection to maximize material separation and SNR, and minimize spectral banding (large FPAs as in MTI [Multispectral Thermal Imager])
  - Model effects of sensor noise, calibration accuracy, GSD, other sensor artifacts, and atmospheric effects on exploitation results
- Simulate error propagation through ICA (Image Chain Analysis), post-processing, and exploitation processes
- Collection Planning
  - Enable scientists to choose sun and viewing angles, SNR, GSD, etc. to satisfy exploitation requirements
  - Optimize sensor collection modes to increase the probability of achieving observation objectives
  - Understand Which Sensors Are Better Suited to A Collection Than Others





Conclusions

- Developed Tools to Allow Simulation of Spectral Sensor Measurements Under a Variety of Conditions
- Simulated Sensor Measurements for a Number of Materials Under Several Sets of Atmospheric Conditions for Landsat-5, Landsat-7 and IKONOS
  - Data Shows Sensors are Very Similar for Many Conditions
  - Largest Variation is in the Red and Near-IR Bands
  - This Has Implications for Comparing NDVI Results Between Sensors
- Tools are Flexible, Extensible, and Immediately Applicable to Additional Sensors, Materials, and Atmospheric Conditions
- Future Work to Include:
  - Modeling of Higher-Order Sensor Effects
    - Effects of Spectral Calibration Errors
    - Effects of Band Misalignment
    - Modulation Transfer Function (MTF) and Point Spread Function (PSF)
    - Higher Fidelity Sensor Noise Model
  - Incorporation of MODTRAN 4.0